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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,329,305**, on December 20, 2000, by **DANIEL CHEVALIER and ALAIN MARTEL**, for "Lighting Device".

S. Grégoire

Agent certificateur/Certifying Officer

December 5, 2001

Date

Canada

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Abstract

The current invention is an intelligent lighting device capable of being connected to a network and being controlled by a host computer also connected to the network.

1. Introduction

This document describes the **Intelligent LED Luminary** system being designed by D llux.

- First, the Luminary itself will be described.
- Second, its integration into a communication network will be described.
- Thirdly, a summary of the advantages of the invention will be given.

1.1 Field of the Invention: Roadway Lighting

The invention proposes to replace existing Roadway Lighting luminaries with luminaries using LEDs (Light Emitting Diodes) as a source of light.

1.2 First planned application: Tunnel Lighting

Because of current LED limitations in terms of light emission intensity, the immediate application of the invention would be in an environment requiring lower, but well controlled, intensities. The first such application we propose to implement is for Tunnel Lighting.

Existing roadway standards for tunnel lighting divide the length of the tunnel into a number of regions. Each region requires a lighting intensity that increases as it is nearer the entrance/exit points (because of the presence of higher illumination from the sun), and decreases towards the middle of the tunnel.

As an example, consider the standard requirements specified by the IESNA (*Illumination Engineers Society of North America*) document RP22-96. The following specifications are typical for the inner section of a tunnel:

- *Illumination Level:*
  Luminance should be at least 5cd/m^2 in daytime, 2.5cd/m^2 in night-time.
- *Illumination Uniformity:*
  Ratio of Average / Minimum luminance should be less than 2.0, ratio of Maximum / Minimum luminance should be less than 3.5.

Our LED Intelligent Luminaries can be used directly in these inner sections (Interior Zone), and also in concert with existing standard luminaries as a hybrid system in the outer sections.

1.3 Current State-of-the-Art

The most common current technology for tunnel lighting uses HID (*High-Intensity Discharge*) lamps, powered with high-voltage (e.g. 300VAC to 400VAC). A typical system will use one 130W lamp per 1.75m per road lane in order to satisfy the daytime specifications required in the Interior Zone of a tunnel.

2. Intelligent LED Luminary Description

2.1 Physical System D scription

The Intelligent LED Luminary is composed of the following parts:

- An array of LEDs;
- An optical system optimizing the LED light output;
- A heat-dissipation system to reduce LED temperature;
- An Electronic Circuit driving the LEDs;
- A sealed case enclosing the above system;
- A Power Supply system (external to the Luminary).

2.1.1 LED Array

The light source of the Luminary is an array of individual LEDs, assembled on one or more printed circuit board sections, perpendicularly to their surface. The number and type of LEDs per section can vary, according to the luminance level required.

As an example, a typical section can contain 780 LEDs, arranged in a rectangular pattern of 26x30 LEDs. A typical Luminary can contain one or more such LED section.

2.1.2. *Lateral Diffusion Control*

Light distribution simulations show that it may be advantageous to spread laterally the light output of the Luminary, in order to obtain a better illuminance uniformity.

The following process can achieve this:

1. Install a number of LED array printed circuit boards (2-1) in the Luminary, in a single line formation;
2. Give a slight tilt angle (2-2) to the LED arrays so that they point towards the sides of the Luminary.

As an example, a typical LED Luminary can contain 2 LED arrays, with a tilt angle of 8° in opposite directions for each printed circuit board.

See Figure 1: Lateral diffusion Control

2.1.3 Heat-Dissipation System

LED light output gradually decreases with usage time. As an example, a typical LED will see its light output decrease by 25% after 100,000 hours. The rate of this degradation increases as the junction temperature of the LED increases. As an example, a typical LED will see the same degradation in 140,000 hours at 25°C as in 110,000 hours at 60°C. It is therefore important to keep the junction temp rature of the LED as low as possible, in order to increase its life expectancy.

It is known that most of the heat generated by a LED (3-1) is dissipated through its leads (3-2). In our LED Luminary we propose to minimize the LED junction temperature by maximizing the transfer of heat through the LED leads. The following process achieves this:

1. Cut the LED leads as they stick out of the solder side of the printed circuit boards to a certain length L (3-9).
2. Fill the space between the LED leads with a compound conductive (3-4) to heat but not to electrical current. This compound will cover the whole surface of the LED Array (3-11), on the solder side of the printed circuit board. The thickness T (3-10) of this compound will be slightly greater than L so that no LED lead extends to its limit.
3. Apply a metallic heat sink (3-5) in contact with the compound mass, to dissipate the heat transferred from the LED leads through the compound. This heat sink can be integrated to the body of the Luminary casing (3-6).

See Figure 2: Heat-Dissipation System

2.1.4 Electronic LED Driver System

The LEDs will be driven by an electronic driver system with the following characteristics:

1. LEDs will be grouped in Chains of equal numbers of LEDs connected in series (4-1). Typical design: C=78 Chains of L=10 LEDs each.

2. All LEDs Chains will be driven by constant current sources (4-2), in order to stabilize their luminosity and to maximize their life expectancy, which degrades faster if the LED current is too high.
3. Each LEDs Chain driver will be under the control of a microprocessor (4-3), which can turn it On or Off.
4. The system will include a means (4-4) to monitor the current flowing through the LEDs Chains, in order to identify defective LEDs.
5. The system will include a means (4-5) to measure the luminosity of a typical LED in its array, in order to regulate the Luminary output luminosity.
6. The system will include a Lamp Status Indicator (4-6) visible from the outside, which will be activated by the microprocessor when the Luminary requires servicing.
7. The system will include a bi-directional communications interface (4-7), through which the Luminary can be linked through a network to a Host computer.
8. The system will have a means (4-8) to set and record a unique network address, so that the Host computer can individually identify each Luminary.

See Figure 3: Electronic LED Driver System

2.1.5 Sealed Case

All the Luminary parts described above are installed in a case (5-1), with a transparent face (5-3) in front of the LED Array (5-4). To ensure long-term reliability the case is environmentally sealed, so that dust and water cannot penetrate inside.

The case has a shape such that when the Luminary is installed in its normal position (e.g. on the ceiling (5-2) of a tunnel facing downwards), its light emission axis (5-7) is tilted by a certain angle (5-5) from the vertical (5-6) towards the incoming traffic (5-8). Light distribution simulations show that this allows optimization of the illuminance.

See Figure 4: Sealed Case

2.1.6 Power Supply System

The Luminary will be powered by a low-voltage source. As an example, a typical Luminary can be powered by 24VDC with a current draw of 4 amperes.

Since the main power source in a tunnel will typically be at 300-400VAC, a step-down adaptor will be used to power the LED Luminaries. A single step-down adaptor unit can be made to power a cluster of LED Luminaries. The number of Luminaries per cluster is chosen so that the total current drawn by the cluster is reasonable, allowing the use of normal power cables.

Possible step-down adaptors include:

- A linear power supply, consisting of a transformer, a rectifier bridge and a filter capacitor;
- A switching power supply;
- A switching power supply with Power Factor Correction.

2.2 *Intelligent Features*

The microprocessor-based design of the LED Luminary will allow the implementation of the following "intelligent" featur s:

2.2.1 Variable Dimming Capability

The output luminosity level of the Luminary will be adjustable by controlling the number of LED Chains turned On or Off (through On/Off Control Outputs 4-9). In our typical design containing 78 individual LEDs Chains per printed circuit board, the luminosity will therefore be continuously adjustable with a resolution of 100/78 = 1.28%.

This method of dimming has the following advantages:

1. *Advantage over proportional control of LED current:*
   It maximizes the life expectancy of the LEDs by always using them at their nominal current, and keeping them On for a smaller proportion of time. This is because LED degradation falls down faster with respect to usage time than it does with respect to current.
2. *Advantage over pulse-width modulation of the LED current:*
   It eliminates power transients and Power Factor problems which could be caused by performing dimming over a large number of Luminaries through pulse-width modulation of the LED current.

2.2.2 Long-Term Luminosity Degradation Compensation

The number of LEDs required to generate the specified luminosity of the Luminary at the start of its life-cycle can be determined using the initial LED specifications. It is known that as the LEDs age, their output luminosity will gradually decrease, or equivalently more LEDs will be required to achieve the specified luminosity.

The LED Array of the Luminary is therefore designed with a number of extra LEDs Chains sufficient to maintain its specified luminosity up to the end of its life-cycle. These extra LEDs Chains will gradually be used by the microprocessor as the Luminary ages.

2.2.3 Light Intensity Self-Regulation

It is known that for a given current, the output luminosity of a LED is dependent on the ambient temperature: LED luminosity is significantly higher at lower temperatures. The invention proposes to stabilize the overall Luminary luminosity under varying ambient temperatures, by implementing a Light Intensity Self-Regulation system.

In addition to the LED Array, this system will use one (or more) Monitor LED (4-10) opto-coupled to a light intensity-measuring device (4-11). The purpose of this system is to evaluate the typical luminosity of the Array LEDs at any given time.

The Monitor LED(s) will be identical to the LEDs used in the Array, supplied with the same constant current (4-12), kept at the same temperature as the Array LEDs, and turned On and Off in such a way as to maintain the same long-term usage rate as the Array LEDs.

The system will preferably use more than one Monitor LED (all of them being driven in parallel), for the following reasons:

1. To prevent failure of the Light Intensity Monitor mechanism should one Monitor LED fail. Although the probability of one LED failing is non-negligible, the probability of more than one failing becomes exceedingly small. The Monitoring system can automatically adapt if it detects an abrupt luminosity transition caused by a Monitor LED failure.
2. To obtain a Monitor luminosity averaged over more LEDs, which will be more representative of the typical luminosity of the Array LEDs.

The light intensity-measuring device (4-11) coupled to the Monitor LEDs (4-10) is read by the microprocessor (4-3). By comparing the Monitor intensity to a reference value, the microprocessor can estimate the LED luminosity variations at any given moment and compensate by adjusting the number of LEDs Chains turned On, thereby regularizing the overall Luminary luminosity.

This will have the following advantages:

- *Better energy efficiency:*
  l ss energy will be required at lower temperatures to achieve the specified luminosity;
- *Better Luminary longevity:*
  fewer LEDs will be used at lower temperatures, thereby minimizing their usage time.

2.2.4 Automatic LED Usage Equalization

At ach stage in the course of the Luminary life, a variable number of LEDs Chains will be On or Off, according to the dimming level requested and the luminosity compensation mechanism. The microprocessor will keep count of the usage time of each of the LEDs Chain in the LED Array, and store these individual usage time values in non-volatile memory (4-13).

When selecting which LEDs Chains to turn On at any given time, the microprocessor will automatically prioritize the use of LEDs Chains having the shortest usage time. This will ensure that all LEDs have an equalized usage time, with no LED degrading faster than others, therefore optimizing the long-term luminosity degradation and stability of the Luminary.

2.2.5 Chain Status Monitoring

The system can monitor on-demand the LEDs integrity by measuring whether any LEDs Chain is open-circuited. A simple way to achieve this function is as follows:

1. Turn Off all LEDs Chains.
2. At the common supply point of all LEDs Chains, install in series with the supply line a test optocoupler (4-4) input LED.
3. Turn On one LEDs Chain; if it functions normally, the current it draws will turn On the test optocoupler. If one or more LED in the Chain is open-circuited, the Chain will draw no current and therefore the test optocoupler will remain Off. The test optocoupler output is monitored by a microprocessor input.
4. Successively turn On each of the LEDs Chains in the LEDs Array and monitor them.

5. Once the t st is finished, remove the test optocoupler from the supply line and resume normal operation.

2.2.6 Lamp Status Indicator

The Luminary is equipped with a Lamp Status Indicator (4-6), visible from the outside of the case. Under control of the microprocessor, this Indicator will provide the following information about the current state of the Luminary:

Indicator State	Status	Description
Off	Normal	Normal operation
Flashing	No Communication	The communication link with the Host PC is lost
On	End of Life	The Luminary can no longer provide its specified luminosity, due to LED failure or degradation.

Table 1: Lamp Status Indicator

2.2.7 Soft Turn-On/Turn-Off

In order to prevent power transients when the tunnel lighting is turned On or Off, or when its dimming level is changed, the microprocessor in each Luminary will automatically make any luminosity transition gradual. This is achieved by turning LEDs Chain On or Off one by one, with a slight time delay between each Chain.

3. Intelligent Luminary Network Description

3.1 Network System Description

An integral part of the Intelligent LED Luminary invention is the linking of a number of Luminaries to a communication network (4-14), and their control by a Host computer through this network. This systems-level aspect of the invention brings a number of further capabilities and features.

Any communication network allowing multidrop connection of a large number of Luminaries to a Host computer is suitable. As an example, the following protocols can be used: RS-485, Ethernet, TCP/IP.

3.2 Communications Network Features

3.2.1 Individual Luminary Address

Each Luminary on the network will be assigned an individual, unique address. The system is designed so that the Host computer keeps a record of the physical location of each Luminary, referenced by its network address.

The address of each Luminary is stored in non-volatile memory (4-13) within its electronic circuit. The Luminary is equipped with an Address Setting Switch (4-8), accessible from the outside of the case. At system installation, this switch is activated to signal to the Host PC that the Luminary is requesting a network address, which is then generated and assigned automatically to the Luminary by the Host PC.

3.2.2 Global Intensity Control

Th Host PC can control the overall, or Global, Intensity level of the lighting area.

3.2.3 Intensity Control by Zone

Because it has individual control over each Luminary, the Host PC can vary the Intensity level for each specific zone of the lighting area. For example, the inner zone of a tunnel can be set to a lower intensity than an outer zone.

The number, size and location of the lighting zones can be easily and arbitrarily modified through the Host software.

3.2.4 Time-of-Day Intensity Control

The Host PC can vary the Intensity level according to the time of day, and/or the ambient luminosity. This level can be optimized on a zone-by-zone basis, with the level in each zone varying according to its luminance needs, in order to maximize energy efficiency.

3.2.5 Gradual Intensity Transitions

When changing from one Intensity level to another, the Host can generate gradual Intensity transitions in order to maximize energy efficiency.

For example, when changing from Night to Day luminance l vels, a discrete control system would have to sel ct the Day level as soon as morning ambient light starts to grow. Instead, the Host PC can perform a gradual ramping between Night and Day l v ls, ther by delaying the increased energy consumption of the Day level and enhancing drivers' visual comfort.

3.2.6 System Status Monitoring

The Host PC will poll each Luminary on the network at regular interval, to obtain its current status information. This information can be tabulated and logged.

- Alarms can be triggered if any potential failure or degradation is detected;
- Maintenance reports can be generated, listing the location and identification of each Luminary requiring servicing.

3.2.7 Fail-Safe Features

1. To prevent the loss of tunnel illumination under any circumstance (short of power failure), each Luminary will automatically revert to its normal Intensity level whenever contact with the Host PC is lost for a time interval longer than an adjustable Communication Time-Out period.
2. In case of power failure, the system can facilitate the generation of emergency lighting backed up by UPS (Uninterruptible Power Supply). The energy consumption can be reduced to a minimum, either by greatly dimming the Luminaries, or by dynamically alternating the Luminaries in the On state.

3.2.8 Vehicle Presence Detection

In order to reduce energy consumption, the Host PC can detect the presence of vehicles in the lighting area (through standard Vehicle Presence Detectors), and dim the Intensity level when no vehicle is present. This dimming can be further refined on a zone-by-zone basis as the vehicle moves across the lighting area.

4. Summary of the advantages of the Invention

4.1 Energy Saving Features

Feature	Explanation
Better light efficiency	• LED inherently more efficient than current HID luminaries; • Optical system further improves efficiency.
Better light uniformity	Luminary optical system optimizes lighting pattern. Since light uniformity is greater, lower overall lighting levels can be used.
Tight Intensity regulation & tolerance	Luminary luminosity is known and stable throughout its life-cycle, allowing lower overall energy dissipation.
Intelligent Proportional Dimming	Allows the use of the optimal intensity required at each moment/location.
Vehicle Presence Detection	Allows dimming when no vehicle is present.

Table 2

4.2 Cost Saving Features

Feature	Explanation
Reduced Usage Costs:	
Competitive Initial Cost	Initial cost equivalent to current HID luminaries.
Lower Energy costs	Higher energy efficiency and usage optimization.
Longer Life-Cycle	LED Luminary life-cycle estimated at 10 years.
Reduced Maintenance Costs:	
Precise Status monitoring through Host	Precludes the need of regular inspections.
Low-Voltage Operation	Allows the use of non-electricians for maintenance.
Fast on-site Identification of defective lamps	Through Status Indicator.

Table 3

Brief description of the drawings.

Fig 1 shows the configuration of two LED arrays according to one of the embodiments of the invention.

Fig 2 show a side view of an LED array having a heat dispersing assembly according to one of the embodiments of the invention.

Fig 3 shows a diagram of the different parts of the invention according to one of the embodiments.

Fig 4 shows the invention mounted on a ceiling according to one of the embodiments.

We claim:

1. A lighting device capable of being connected to a network.

2. A lighting device capable of being connected to a network, substantially as decribed herein.

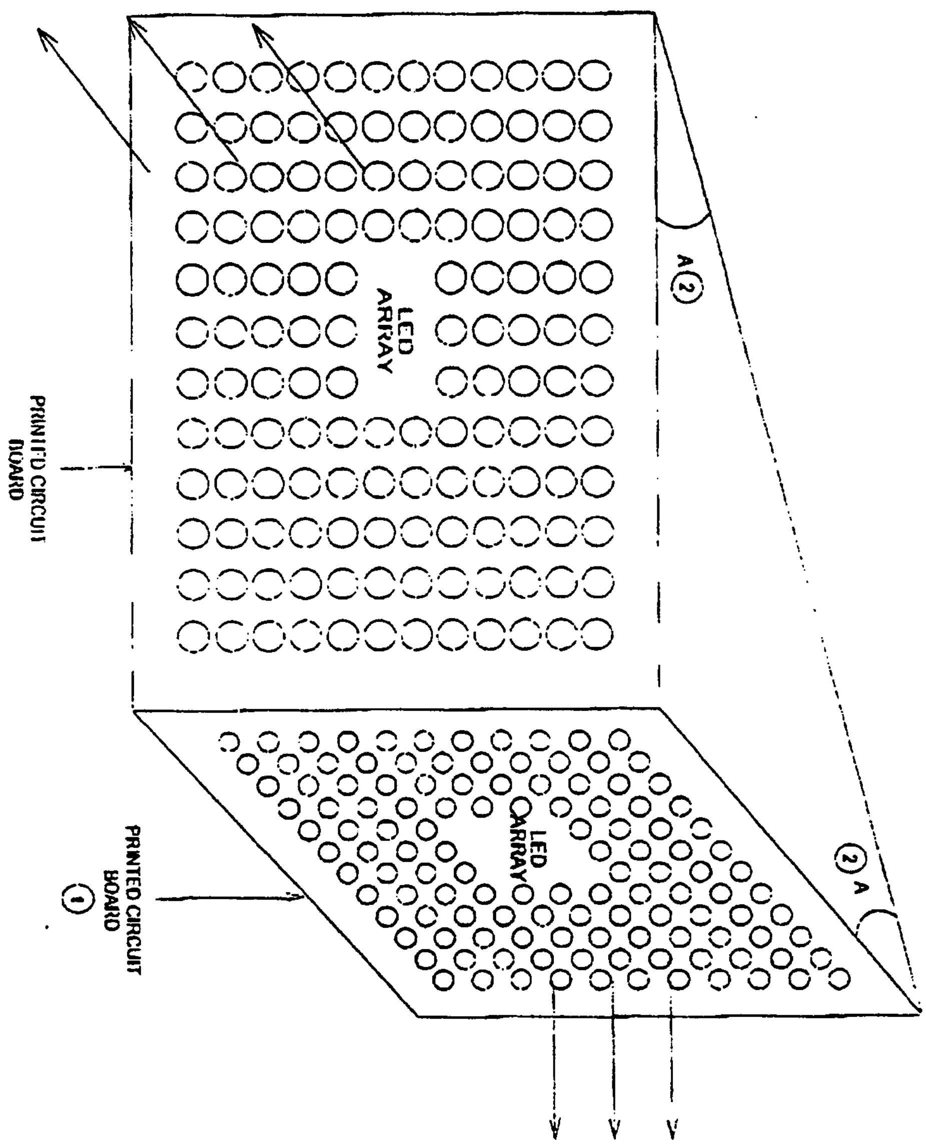
LED ARRAY
PRINTED CIRCUIT BOARD
1
A 2
LED ARRAY
PRINTED CIRCUIT BOARD
1
2 A

Fig 1

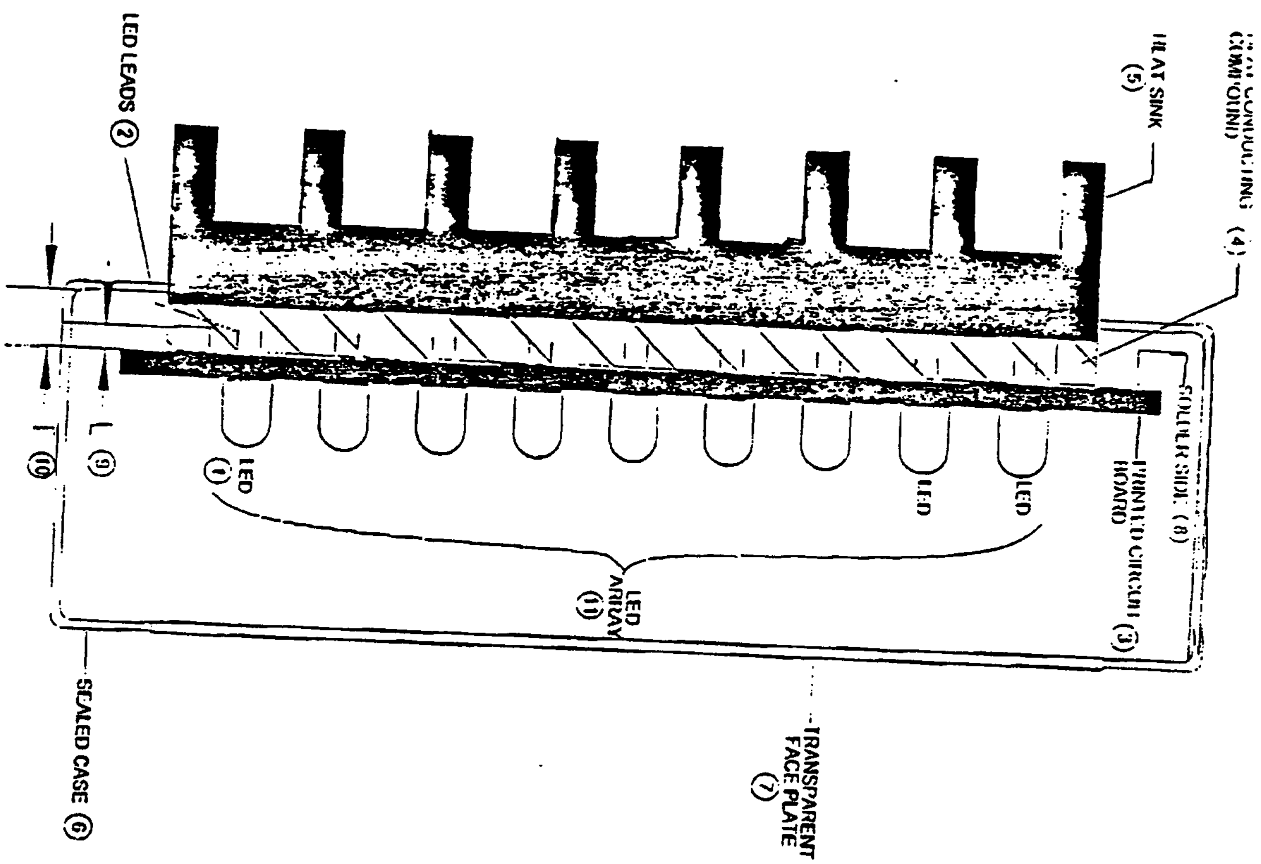
COMPOUND (4)
HEAT SINK (5)
LED LEADS (2)
SOLDER SIDE (8)
PRINTED CIRCUIT BOARD (3)
LED (1)
LED
LED
LED ARRAY (11)
TRANSPARENT FACE PLATE (7)
SEALED CASE (6)
9
10

Fig 2

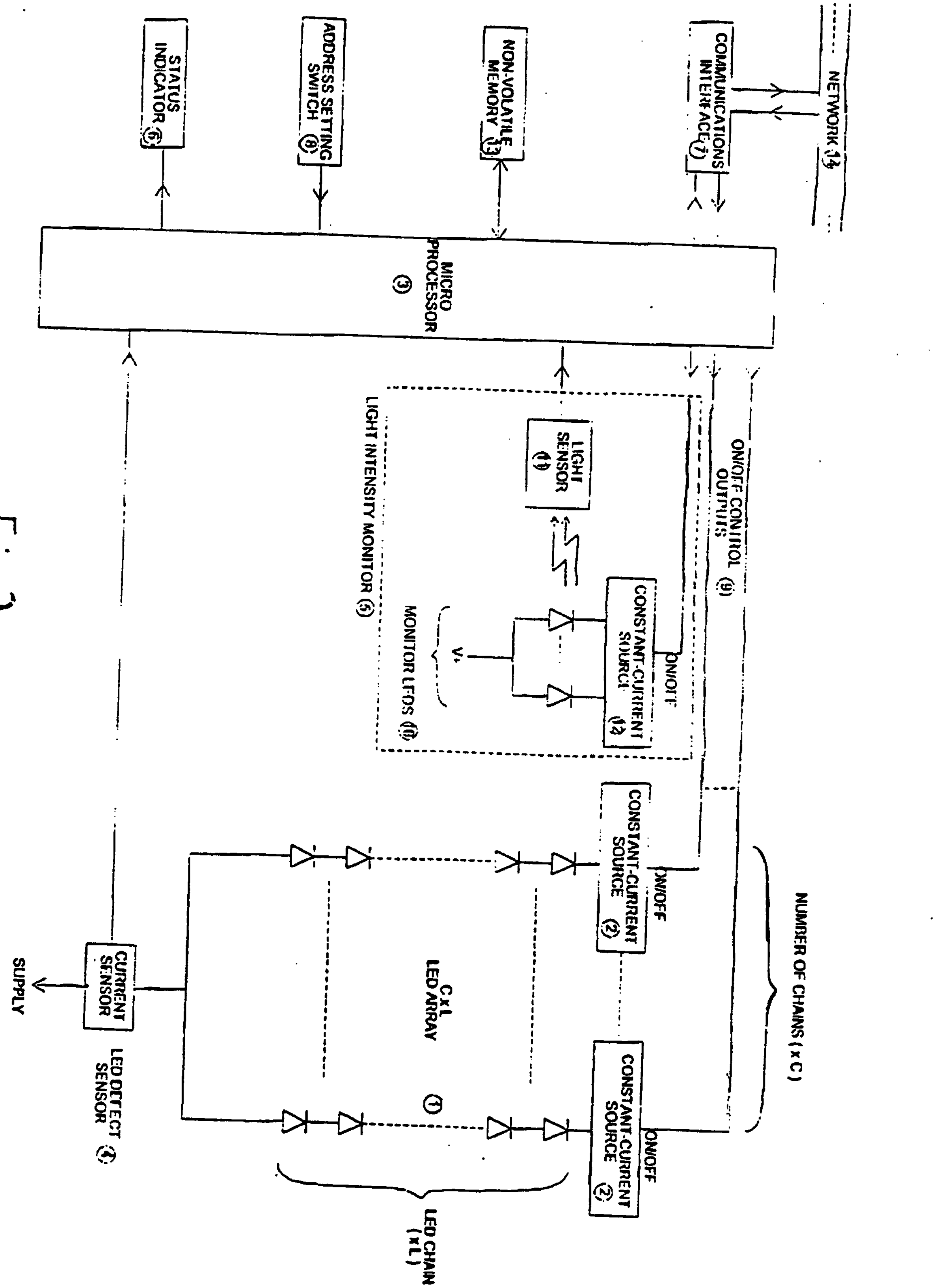
NETWORK (14)
COMMUNICATIONS INTERFACE (7)
NON-VOLATILE MEMORY (13)
ADDRESS SETTING SWITCH (8)
STATUS INDICATOR (6)
MICRO PROCESSOR (3)
ON/OFF CONTROL OUTPUTS (9)
LIGHT SENSOR (11)
ON/OFF
CONSTANT-CURRENT SOURCE (12)
V+
MONITOR LEDS (10)
LIGHT INTENSITY MONITOR (5)
NUMBER OF CHAINS (x C)
ON/OFF
CONSTANT-CURRENT SOURCE (2)
ON/OFF
CONSTANT-CURRENT SOURCE (2)
C x L LED ARRAY (1)
LED CHAIN (x L)
CURRENT SENSOR
SUPPLY
LED DEFECT SENSOR (4)

Fig 3

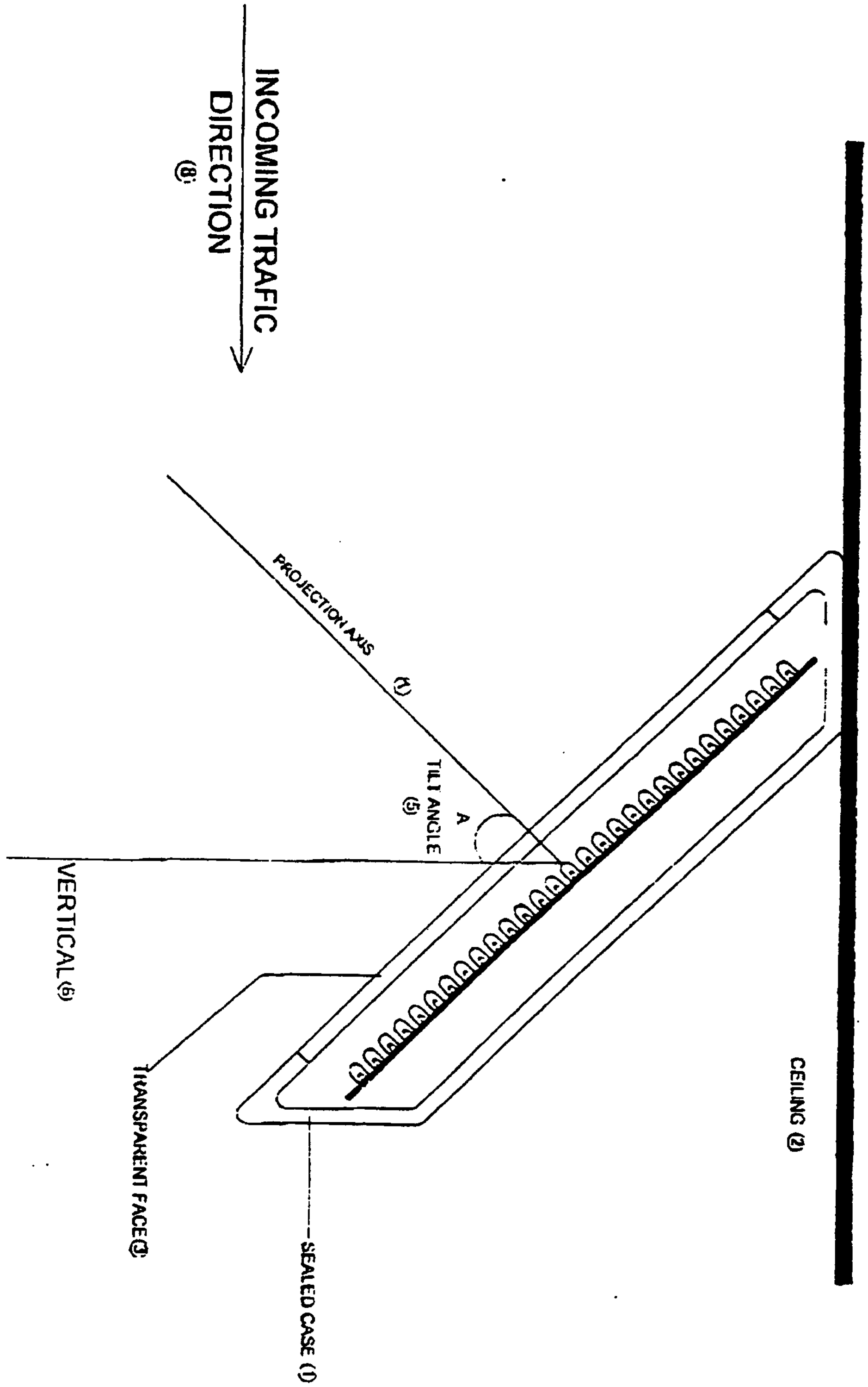
INCOMING TRAFIC DIRECTION
(8)
PROJECTION AXIS
(7)
A
TILT ANGLE
(5)
VERTICAL (6)
TRANSPARENT FACE (3)
SEALED CASE (1)
CEILING (2)

Fig 4